REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-00-

0591

1. REPORT DATE (DD-MM-YYYY) 12 October, 2000	2. REPORT TYPE ~~Technical~~ Final report	3/1/97-2/28/98
4. TITLE AND SUBTITLE Integrated Instrumentation for Electro-optic Polymer Development		5a. CONTRACT NUMBER
		5b. GRANT NUMBER F49620-97-1-0124
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Alex K-Y. Jen Current Address: Dept. of Materials Science & Engineering, Box 352120 University of Washington, Seattle, WA 98195-2120		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Northeastern University	Department of Chemistry Northeastern University Boston, MA 02115	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dr. Charles Y-C. Lee AFOSR/NL 801 N. Randolph St. #732 Arlington, VA 22203-1977		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

We have developed an integrated instrumentation to demonstrate and implement a test procedure that enhanced the development of suitable polymeric E-O materials for integrated optics. The material test requirements were based on the fabrication, assembly, and end use product requirements of the material in a device. The sequential test procedure is consist of a series of tests designed to efficiently test and screen materials as they are being developed. The test targets a simple integrated optic device to measure a wide range of performance values, while the compatibility of the material will be evaluated during the fabrication of the test device. The development of an enhanced material system will demonstrate the usefulness of the procedure. The test methods have been transfer to the material development community.

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15. SUBJECT TERMS

ELECTRO-OPTIC, POLYMER

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE		8	Alex K-Y. Jen
Unclas	Unclas	Unclas			19b. TELEPHONE NUMBER (include area code) (206) 543-2626

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

END-OF-THE-YEAR-REPORT

for

GRANT #, F49620-97-1-0124

Integrated Instrumentation for Electro-optic Polymer Development

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1. Introduction

A major driving force for optical connections is that optical pulses are unaffected by electrical capacitance that delays electrical pulses, allowing operation at higher clock rates. Before optical interconnections become practical, affordable optical switches and fast opto-electronic conversion devices need to be developed. Polymeric nonlinear optical materials offer exciting new opportunities in integrated nonlinear optics. In particular, electro-optic (E-O) polymeric materials exhibit low dispersion and low dielectric constants. E-O polymers have been modulated to 60 GHz and exhibit few fundamental limits for ultra fast modulation and switching. Polymeric integrated optical materials also offer great fabrication flexibility in electronic systems applications. High levels of integration have been demonstrated with polymers by using multiple layers of wave guides as well as in-plane and out-of plane mirrors. The potential for low-cost manufacturing, packaging, and assembly arises from the demonstrated ability to perform hybrid integration of single-mode components using lithographically-defined registration techniques. Advanced products include components for "flight-by-light" and phase array radar applications, opto-isolators for semiconductor test fixture applications, impedance matching fan out modules, processor multichip modules with high bandwidth interfaces between CPU and second-level cache, and 8-12 bit, high-speed A-D's. Electro-optic polymers are unique in offering this level of product potential. However, despite the exciting promise of these materials, only laboratory demonstrations have occurred.

A number of different groups are developing the basic NLO molecules, polymeric materials, processes, and devices. These different groups measure and report their results based on different specific and individual tests. There is no accepted test procedure to compare results and compare these to what is needed for a functioning device. Due to the different test procedures and measurement methods employed, it is difficult to make comparisons between the materials. Thus, selecting the most promising development path becomes difficult.

To further compound the problem, results reported in the literature for new materials do not measure all the properties relevant for practical systems. The data reported for new systems can not be compared because no consistent sets of measurements are used. The material development progress for the entire field is thus retarded because of the lack of a consistent test methodology to guide the development of E-O polymers for integrated optics.

2. Objective

The objective for developing an integrated instrumentation is to demonstrate and implement a test procedure that will enhance the development of suitable polymeric E-O materials for integrated optics. The material test requirements are based on the fabrication, assembly, and end use product requirements of the material in a device. The sequential test

procedure is consist of a series of tests designed to efficiently test and screen materials as they are being developed. The test targets a simple integrated optic device to measure a wide range of performance values, while the compatibility of the material is evaluated during the fabrication of the test device. The development of an enhanced material system will demonstrate the usefulness of the procedure. The test methods have been transfer to the material development community.

3. Impact on the new research program of E-O materials at the Northeastern University

This integrated instrumentation has greatly enhanced the capability of the new E-O materials research facility at the Northeastern University to evaluate the E-O material system properties. The new facility established by Professor Alex Jen possesses the capability of performing the electric field induced second harmonic generation (EFISH) measurements for determining the molecular hyperpolarizability ($\beta\mu$) of the NLO chromophores. This facility is also equipped with the instruments such as TGA and DSC for thermal analysis; GPC and HPLC for polymer molecular weight measurement; and Dektak instrument for measuring thin film thickness. In addition, FT-IR and UV-Vis-Near IR spectrometer are used to determine the thermal stability of the E-O polymer thin films. This integrated instrumentation has helped to bridge between the effort of evaluating NLO chromophore molecular studies, and E-O polymeric material system properties, and thus, directly impact the fabrication of waveguide structures for device applications. More than twenty electro-optic materials related papers have been published in the refereed journals based on the characterization results derived from this set-up. In addition, this facility has provided very useful services to researchers (Professor Seth Marder-University of Arizona, Professor Larry Dalton-USC, Professor James Bu-Clark-Atlanta University, and Dr. O. K. Kim-ONR) that are supported by the DoD's funding agency. The capability of this integrated instrumentation includes the spin-coating of uniform polymer thin films, measurements of both TM and TE refractive indices, optical loss, and electro-optic coefficients of poled E-O polymers at various wavelengths of device interest.

4. Interface between the instrumentation and the facility for light-emitting (LED) materials research at the Northeastern University

This integrated instrumentation interfaces very well with the LED materials research facility at Northeastern University (NU) to jointly evaluate organic photonic/opto-electronic material properties. One of the new research program proposed by both professors Alex Jen and Yang Yang (UCLA) aims at demonstrating an integrated all polymer LED/E-O device by using organic conjugated polymers as both a light source (LED) and a photo-detector, and using NLO

polymer channel waveguides as an E-O switching device. This instrumentation greatly enhances the capability of quickly developing/screening E-O materials systems to ensure the greatest chance of success. In the areas of optical and electrical characterization, the micromanupilator device could be used to cure (up to 400 °C) and pole NLO thin films and channel waveguides; Metricon prism coupler could measure refractive index, optical loss, and thickness of polymer thin films; lock-in amplifier and the associated electronic system could measure optical and electro-optic signal generated by LED/E-O materials. This integrated instrumentation will help to bridge between the effort of evaluating E-O and LED polymeric material system properties, and thus, directly impact the fabrication of all polymer LED/E-O devices.

5. Research training of students

The highly interdisciplinary nature of the program to develop high performance E-O materials for device applications, the outstanding faculty and institutions involved, and connections with high technology device companies and DOD laboratories ensure a rich educational environment for the graduate students, postdoctoral, and undergraduate students involved. Students will be active members involved in closely integrated material synthesis, characterization, and device fabrication. Students associated with this program will emerge with a unique background and complement of skills. The ability to communicate with and work with academic, government, and industrial researchers in other disciplines towards a common goal will uniquely qualify them for the technical workforce of the future.

6. Publications that acknowledge the AFOSR

1. "Design and Synthesis of Chromophores and Polymers for Electro-optic and Photorefractive Applications", S. R. Marder, B. Kippelen, A. K-Y. Jen, and N. Peyghambarian, Nature, 1997, **388**, 845.

2. "Recent Progress of Electro-optic Polymers for Device Applications", A. K-Y. Jen, S. R. Marder, and C. F. Shu, Polymer Preprints, 1997, **38(2)**, 495.

3. "High Performance Chromophores and Polymers for Electro-optic Applications", A. K-Y. Jen, Technical Abstracts, The Seventh International Kyoto Conference on New Aspects of Organic Chemistry, 1997, 25.

4. "Recent Development of Highly Efficient Chromophores and Polymers for Electro-optic Device Applications", A. K-Y. Jen, Q. Yang, S. R. Marder, L. R. Dalton, and C. F. Shu, Mat. Res. Soc. Proc., 1998, **488**, 193.

5. "High Performance Polyquinolines with Pendent High Temperature Chromophores for Second Order Nonlinear Optics", A. K-Y. Jen, X. M. Wu, and H. Ma, Chem. Mater., 1998, **10**, 471.

6. "A versatile Synthetic Approach to Nonlinear Optical Side-chain Aromatic Polyquinolines with Large Second-order Nonlinearity and Thermal Stability", H. Ma, X. Wang, X. Wu, S. Liu, and A. K-Y. Jen, Macromolecules, 1998, **31(12)**, 4049.

7. "Synthesis of Novel Nonlinear Optical Chromophores", X. Wu and A. K-Y. Jen, Polymer Preprint, 1998, **39(2)**, 1091.

8. "A Versatile Approach for the Synthesis of Side-chain Aromatic Polyquinolines for E-O Devices", H. Ma, S. Liu, X. M. Wu, X. Wang, and A. K-Y. Jen, Polymer Preprint, 1998, **39(2)**, 1109.

9. "Two Photon Absorption, Fluorescence, and Scattering of Nonlinear Optical Materials", C. H. Wang, M. A. Pauley, J. N. Woodford, and A. K-Y. Jen, Polymer Preprint, 1998, **39(2)**, 1132.

10. "NLO Chromophores with Configuration-locked Polyene Possessing Enhanced Thermal and Chemical Stability", C. Shu, Y-C. Shu, Z-H. Gong, S-M. Peng, G-H. Lee, and A. K-Y. Jen, Chem. Mater. 1998, **10(11)**, 3284..

11. "Design and Synthesis of Highly Efficient Chromophores and Polymers for Electro-optic Applications", A. K-Y. Jen, H. Ma, X. Wu, J. Wu, S. Liu, P. Herguth, S. R. Marder, C. F. Shu and L. R. Dalton, Nonlinear Optics, 1999, **22**, 9.

12. "Synthesis and Characterization of Highly Efficient, Chemically and Thermally Stable Chromophores with Chromone-containing Electron Acceptors for Nonlinear Optical Applications", A. K-Y. Jen, Y. Liu, L. Zheng, S. Liu, K. J. Drost, and Y. Zhang, Adv. Mater., 1999, **11(6)**, 452.

13. "Highly Efficient, Thermally and Chemically Stable Second-order Nonlinear Optical Chromophores with a 2-Phenyl-tetracyanobutadienyl Acceptor", X. Wu, J. Wu, and A. K-Y. Jen, J. Am. Chem. Soc., 1999, **121(2)**, 472.

14. "A Modular Approach of Functionalizing Aromatic Polyquinolines for Electro-optic Devices", H. Ma, A. K-Y. Jen, J. Wu, X. Wu, S. Liu, C-F. Shu, L. R. Dalton, S. Thayumanavan and S. R. Marder, Chem. Mater. 1999, **11**, 2218.

15. "The Molecular and Supramolecular Engineering of Polymeric Electro-optic Materials", B. H. Robinson, L. R. Dalton, A. W. Harper, A. Ren, F. Wang, C. Zhang, G. Todrovac, M. Lee, R. Aniszfeld, S. Garnerd, A. Chen, W. H. Steier, S. Houbrechte, A. Persoon, I. Ledoux, J. Zyss, and A. K-Y. Jen, Chem. Phys., 1999, **245**, 35.

16. “Recent Progress of Highly Efficient Chromophores and Polymers for Electro-optic Devices”, A. K-Y. Jen, H. Ma, X-M. Wu, J-Y. Wu, S. Liu, S. R. Marder, L. R. Dalton and C-F. Shu, Proc.SPIE, 1999, **3623**, 112.

17. “Synthesis and Characterization of Nonlinear Optical Chromophores with Conformation-locked Polyenes Possessing Enhanced Thermal Stability”, Y. Shu, Z-H. Gong, C-F. Shu, E. M. Breitung, R. J. McMahon, G-H. Lee and A. K-Y. Jen, Chem. Mater., 1999, **11**, 1628.

18. “Electro-optic Polymers and Applications: Materials Based on Heteroaromatic NLO Chromophores”, A. K-Y. Jen, and Y. Zhang, Book Chapter in “Photonic Polymer Systems” Edited by Donald Wise and Gary Wnek, Marcel Dekker Publishers, 1998, 847.

19. "From Molecules to Opto-Chips: Organic Electro-Optic Materials," L. R. Dalton, L. Irwin, B. Carlson, F. Fiffield, G. Phelan, C. Kincaid, J. Amend, C. Zhang, A. Ren, M. Lee, G. Todorov, S. M. Garner, A. Chen, W. H. Steier, H. Fetterman, and A. K. Y. Jen, J. Mater. Chem., 1999. **9**, 1905.

20. “Polyquinolines: Multifunctional Polymers for Electro-optic and Light-emitting Applications”, A. K-Y. Jen and H. Ma, Mat. Res. Soc. Proc. (in press).

21. “Highly Efficient, Thermally and Chemically Stable Nonlinear Optical Chromophores Based on The α-Perfluoroaryl-dicyanovinyl Electron Acceptors”, X. Wu, J. Wu, Y. Liu and A. K-Y. Jen, Chem. Commun., 1999, **23**, 2391.

22. “Realization of Polymeric Electro-optic Modulators with Less Than one Volt Drive Voltage Requirement”, C. Zhang, M. Lee, A. Winkleman, H. Northcroft, C. Lindsey, A. K-Y. Jen, T. Londergan, W. H. Steier, and L. R. Dalton, Mat. Res. Soc. Proc., 1999, xxx.

23. “Thermal Poling of Soda-Lime Glass for hybrid Glass/Polymer Electro-optic Modulators”, Y. Enami, P. Poyhonen, D. Mathine, A. Bashar, M. Paratheepan, S. R. Marder, S. Honkanen, B. Kippelen, N. Peyghambarian, A. K-Y. Jen, J. Wu, Appl. Phys. Lett., 2000, **76(9)**, 1086.

24. “A Novel Class of High Performance Perfluorocyclobutane-Containing Polymers for Second-Order Nonlinear Optics”, H. Ma, J. Wu, P. Herguth, B. Chen and A. K-Y. Jen, Chem. Mater., 2000, **12**, 1187.

25. “Novel Perfluorocyclobutane-Containing Thermoset Polymers and Dendrimers for Electro-Optic Devices”, H. Ma, B. Chen, L. R. Dalton, and A. K-Y. Jen, Poly. Mater. Sci. Eng., 2000, **83**, 165.

Purchased Equipment

Equipment	Model	Unit Price	Totals	Vender and Address
Lock-in Amplifier				Stanford Research Systems 1290-D Reamwood Ave. Sunnyvale, CA 94089 Tel: (408)744-9040 Fax: (408)744-9049
SRS Lock-In Amplifier	SR850	$ 7,500.00		
FET Input Preamplifier	SR550	$ 495.00		
Bipolar Input Amplifier	SR552	$ 495.00		
Transformer Preamplifier	SR554	$ 995.00		
Carrying Handle	O760H	$ 100.00		
Sub Total			**$ 9,585.00**	
Function Generator				
Function Generator	DS345	$ 1,595.00		
GPIB and RS-232 Interface	Option 01	$ 495.00		
High Stability Timebase	Option 02	$ 650.00		
Sub Total			**$ 2,740.00**	
Low Noise Preamplifier				
Low Noise Preamplifier	SR 560	$ 1,895.00		
Sub Total			**$ 1,895.00**	
Optical Chopper				
Optical Chopper	SR 540	$ 995.00		
Replacement Chopper Head	0540RCH	$ 220.00		
Sub Total			**$ 1,215.00**	
High Voltage Power Supply				
High Voltage DC Power Supply	PS350	$ 1,150.00		
GPIB Interface	Opt. 01	$ 495.00		
Sub Total			**$ 1,645.00**	
High Voltage Supply/Amplifier/Control	610C	$ 4,095.00		Trek 3932 Salt Works Rd. Medina, NY 14103
Sub Total			**$ 4,095.00**	
Compensator				Melles Griot 1770 Kettering St. Irvine, CA 92714 Tel: (800)835-2626 Fax: (714)261-7589
Soleil-Babinet Compensator	04SBC001	$ 4,069.00		
Sub Total			**$ 4,069.00**	
Polarizers				
Glen-Taylor Polarizing Prism (2)	03PGL301	$ 726.00		
Prism Holder (2)	07HPR003	$ 260.00		
Sub Total			**$ 1,972.00**	
Rotation Control System				AEROTech 101 Zeta Dr. Pittsburger, PA 15238 Tel: (412)963-7470 Fax: (412)963-7459
Rotational Stage	ART301	$ 747.00		
Unidex Motion Controller	U11x-4-A-vvv	$ 4,885.00		
GPIB Card		$ 495.00		
LabVIEW Software	LabVIEW	$ 1,995.00		
Sub Total			**$ 8,122.00**	
Light Sources				Laser Max 3495 Winton Place, Bldg. B Rochester, NY 14623 Tel: (716)272-5420 Fax: (716)272-5427
Diode Laser, 830 nm	Las-300-830-20	$ 4,500.00		
Diode Laser, 1300 nm	Las-300-1300-20	$ 3,800.00		
Diode Laser, 1550 nm	Las-300-1550-20	$ 4,600.00		
Sub Total			**$ 12,900.00**	

CV Probing Test Stations				Micromanipulator
Test station	D6	$ 17,050.00		1555 Forrest Way
Accessary		$ 1,000.00		Carson, NV 89706
Sub Total			$ 18,050.00	Tel: (702)882-7377
Prism Coupler				Metricon Corporation
Metricon 2010 Prism Coupler	2010	$ 28,500.00		P.O.Box 63
Prism, low index	200-P-1	$ 750.00		Pennington, NJ 08534
Prism, high index	200-P-2	$ 750.00		Tel: (609)737-1052
Prism, broad index	200-P-3	$ 750.00		Fax: (609)737-1567
Prism, broad index	200-P-4	$ 750.00		
TM mode option	2010-TM	$ 1,250.00		
Non-contact thickness	2010-VO	$ 3,000.00		
measurement	2010-NSW-1550	$ 5,200.00		
Diode laser, nominal 1550 nm	2010-NSW-1300	$ 3,800.00		
Diode laser, nominal 1300 nm	2010-NSW-830	$ 4,000.00		
Diode laser, nominal 830 nm	2010-SBL-IR	$ 1,500.00		
Secondary Input Port	2010-GE	$ 1,200.00		
Germanium Detector	2010-WGL2	$ 5,300.00		
Waveguide loss measurement option				
Sub Total			$ 56,750.00	
Optical Table				Newport Corporation
Optical Table	RS3000-512-12	$ 11,775.00		1791 Deere Ave.
Table legs (4)	I-2000	$ 3,455.00		Irvine, CA 92714
Overhead Table Shelf System	ATS-12	$ 2,091.00		Tel: (800)222-6440
Sub Total			$ 17,321.00	Fax: (714)253-1680
Spin Coater (cost shared)				Solitec, Inc.
Single-head coater	5110-CT	$ 22,070.00		3901 Burton Dr.
Sub Total			$ 22,070.00	Santa Clara, CA 95054
		Total Equipment Cost	**$ 162,429.00**	
		COST SHARE	**$ (22,070.00)**	
		Total Funding Requested from AFOSR	**$ 140,359.00**	